

PREDICTION OF CHATTER IN CNC MACHINING BASED  
ON DYNAMIC CUTTING FORCE MODEL FOR BALL END  
MILLING

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PREDICTION OF CHATTER IN CNC MACHINING BASED ON DYNAMIC  
CUTTING FORCE FOR BALL END MILLING

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### **STUDENT'S DECLARATION**

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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*To my beloved father and mother,*

*Hasfa bin Onong*

*Hajjah binti Hj Ali,*

*My brothers and sister*

*And to all my beloved friends*

## **ACKNOWLEDGEMENT**

By the name of ALLAH, the Most Gracious and Most Merciful

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## **ABSTRACT**

This paper presents the suitable depth of cut, spindle speed and feed rate that will be chosen during machining. If these parameters are not considered, this can provoke abnormal tool behavior such as chatter. Chatter will limit the tool life which only can be used for just a few times. To predict the chatter occurs, the parameters that will be used are spindle speed, depth of cut and feed rate. CNC machine will be used. This process will be based on dynamic cutting force model for ball end milling. The selection of cutting tool depends on the process that will be done where the chatter can be observed during this machining process. Cold work tool steel (AISI-D2) chosen as a material and its parameter is 100x100x25 mm. Cutter used was high speed steel 2 flute ball nose. Force dynamometer will be used to measure force and 27 tests will be done to observe the chatter occur. Analysis done by referring the result that measured by force dynamometer. The chatter in ball end milling can be detected from the calculated cutting forces and their frequency spectra. A comparison of the predicted and measured cutting forces demonstrated that the proposed method provides accurate results.

## **ABSTRAK**

Kertas ini membentangkan ukur dalam potong sesuai, kelajuan gelendong dan kadar suapan yang akan terpilih sepanjang memesis. Sekiranya parameter ini tidak dipilih dengan betul, ini akan menyebabkan berlakunya ketidakstabilan ke atas pemotong contohnya getaran yang teruk. Getaran menghadkan jangka hayat pemotong dimana hanya boleh guna untuk beberapa kali sahaja. Untuk menjangka getaran akan berlaku, parameter yang akan digunakan adalah ukur dalam potong sesuai, kelajuan gelendong dan kadar suapan. Mesin CNC akan digunakan dalam proses tersebut. Proses ini akan berteraskan dinamik model daya memotong untuk pemotong mata bulat. Pemilihan-pemilihan perkakas pemotongan adalah bergantung kepada proses kehendak itu dibuat dimana getaran akan berlaku dan boleh dilihat. Bahan kerja yang dipilih untuk menjalankan proses ini adalah Cold work tool steel (AISI-D2) yang bersaiz 100x100x25 mm. pemotong yang digunakan pula adalah, keluli berkelajuan tinggi yang mempunyai potongan mata yang bulat. Satu perbandingan diramal dan kuasa-kuasa memotong yang diukur ditunjukkan dengan kaedah yang dicadangkan menyediakan hasil-hasil tepat.



## **TABLE OF CONTENTS**

	<b>Page</b>
<b>SUPERVISOR'S DECLARATION</b>	i
<b>STUDENT'S DECLARATION</b>	ii
<b>ACKNOWLEDGEMENT</b>	iii
<b>ABSTRACT</b>	iv
<b>ABSTRAK</b>	v
<b>TABLE OF CONTENTS</b>	vi
<b>LIST OF TABLES</b>	ix
<b>LIST OF FIGURES</b>	ix
<b>LIST OF ABBREVIATIONS</b>	xi

### **CHAPTER 1 INTRODUCTION**

1.1	Project Background	1
1.2	Project title	2
1.3	Problem Statement	2
1.4	Objective Of Research	2
1.5	Scopes	2
1.6	Project Flow Chart	3

### **CHAPTER 2 LITERATURE REVIEW**

2.1	Introduction	4
2.2	Chatter	5
2.3	Dynamic Cutting Force	6
2.4	Ball end milling	7
2.5	Types of cutter	8

2.6	End mill tool	9
2.7	End mill technical feature	12
2.8	CNC machine	17
	2.8.1 CNC machine component	18
	2.8.1.1 CNC control	19
	2.8.1.2 Frame	19
	2.8.1.3 Headstock	19
	2.8.1.4 Spindle/Tool taper	20
	2.8.1.5 Tablet/Pillet	20
	2.8.1.6. Tool magazine	20
	2.8.1.7 Tool setter	21
	2.8.2 Classification of CNC system	21
	2.8.2.1 Straight cut system	21
	2.8.2.2 Continuous path system	21
	2.8.2.3 Closed loop system	22
	2.8.3 CNC machine option	22
	2.8.4 Spindle speed	23
	2.8.5 Advantages of CNC machine tool	23

### **CHAPTER 3 DURABILITY ASSESSMENT METHODS**

3.1	Introduction	24
3.2	Table of experiment	25
3.3	Determine Material, Method and Machining Parameters	26
3.4	Machining Process	27
3.5	Result Analysis	29

## **CHAPTER 4      RESULTS AND DISCUSSION**

4.1	Introduction	30
4.2	Preliminary finding research	30
4.3	Result of cutting forces	31
4.4	Graph result taken from Kitsler® Dynoware for number of test 1	33
4.5	Graph result taken from Kitsler® Dynoware for number of test 7	35
4.6	Graph result taken from Kitsler® Dynoware for number of test 27	37
4.7	Cutting force $F_x$ versus depth of cut (mm) with feed rate 300 mm/min	39
4.8	Discussion on graph from Kitsler® Dynoware	49
4.9	Recommendation of Reducing Chatter Vibration	50

## **CHAPTER 5      CONCLUSION AND RECOMMENDATIONS**

5.1	Introduction	51
5.2	Conclusions	51
5.3	Suggestion for Improvement	52

<b>REFERENCES</b>	53
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### **APPENDICES**

A	Table and Project flow diagram	54
B	Instrumentation	58

## **LIST OF TABLES**

<b>Table No.</b>		<b>Page</b>
3.1	Design of Experiment Table	25
4.1	Cutting force in x, y-direction	31

## **LIST OF FIGURES**

<b>Figure No.</b>		<b>Page</b>
1.1	Project flow chart	3
2.1	Cutting Force Model	7
2.2	HSS 2-flute ball end mill	8
2.3	End Mill Criteria	9
2.4	Part of Flute	11
2.5	Part of Cutting Tool	12
2.6	Angle of Cutting Tool	13
2.7	Part of Rake Angle	15
2.8	Secondary Angle of Cutting Tool	16
2.9	CNC vertical machining center	18
2.10	CNC horizontal machining center	18
2.11	Closed loop control system	22

3.1	Procedure Flow Diagram	24
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**Continue List of Figure:**

<b>Figure No.</b>		<b>Page</b>
3.2	CAD design of workpiece for machining	28
4.1	Cutting force $F_x$ (N) versus time (s)	33
4.2	Cutting Force $F_y$ (N) versus Time (s)	34
4.3	Graph cutting force $F_x$ (N) versus Time (s)	35
4.4	Graph cutting force $F_y$ (N) versus Time (s)	36
4.5	Graph cutting force $F_x$ (N) versus Time (s)	37
4.6	Graph cutting force $F_y$ (N) versus Time (s)	38
4.7	Cutting force $F_x$ versus depth of cut (mm) with feed rate 300 mm/min	39
4.8	Cutting force $F_y$ (N) versus depth of cut (mm) with feed rate 300mm/min	41
4.9	Cutting force $F_x$ (N) versus depth of cut (mm) with feed rate 400mm/min	42
4.10	Cutting force $F_y$ (N) versus depth of cut (mm) with feed rate 400mm/min	44
4.11	Cutting force $F_x$ (N) versus depth of cut (mm) with feed rate 500mm/min	46
4.12	Cutting force $F_y$ (N) versus depth of cut (mm) with feed rate 500mm/min	47

## **LIST OF ABBREVIATIONS**

CNC	Computer Numerical Control
CAD	Computer-aided drafting
CAM	Computer-aided Manufacturing
MCU	Machine Control Unit
MDI	Manual Data Input
NC	Numerical Control

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Project background**

The metal removing and cutting process has long been known as one of the most important and widely used in process in manufacturing industry. In modern cutting technology, milling process has enrolled a place as one of the essential metal removal and cutting processes in manufacturing and fabricating products especially in producing high-precision parts and also die and mould machining. The efficiency of machining operation especially milling process is always determined by the material removal rate, tool wear and cycle time. The milling process is most efficient if the material removal rate is as large as possible, while maintaining a high quality level. Optimizing chip removal will ensure without sacrificing product quality.

The paper contains a practical on prediction of machine tool chatter. As a consequence of this research, a significant factor that contributes to this undesirable chatter occurrence during end milling cutting tools will be determined by using ANOVA. Those results will represent stability information by defining between stable chatter-free region and unstable region. Optimization of material removal rate with less chatter occurrences for mild steel (AISI-D2) milling operation also can be achieved by varying cutting parameters for instance, depth of cut and spindle speed. Certain combination of spindle speed (rpm) and depth of cut (mm) can introduce stable condition during machining.

## **1.2 Project title**

Prediction of chatter in CNC machining based on dynamic cutting force for ball end milling.

## **1.3 Problem Statement**

1. Unstable chatter vibration occurrences due to interaction of end mill cutter tool and workpiece in end milling.
2. Higher percentage of chatter vibration in end milling process as a function to increase metal removal rate.

## **1.4 Objective Of Research**

1. To predict chatter occur based on spindle speed, feed rate and depth of cut in CNC machine for ball end mill.
2. To predict the most significant parameters between spindle speeds, depth of cut and feed rate which contribute to occurrence of chatter during end milling machining on mild steel AISI D2.

## **1.5 Scopes**

1. Predict chatter of end milling operation on Cold work tool steel (AISI-D2).
2. Measure on what time that chatter will occur with different parameters by using Kistler<sup>®</sup> force Dynamometer to obtain result value and force time graphical data during machining operation.
3. Study the parameters that give big influence in machining.



## 1.6 Project Flow Chart

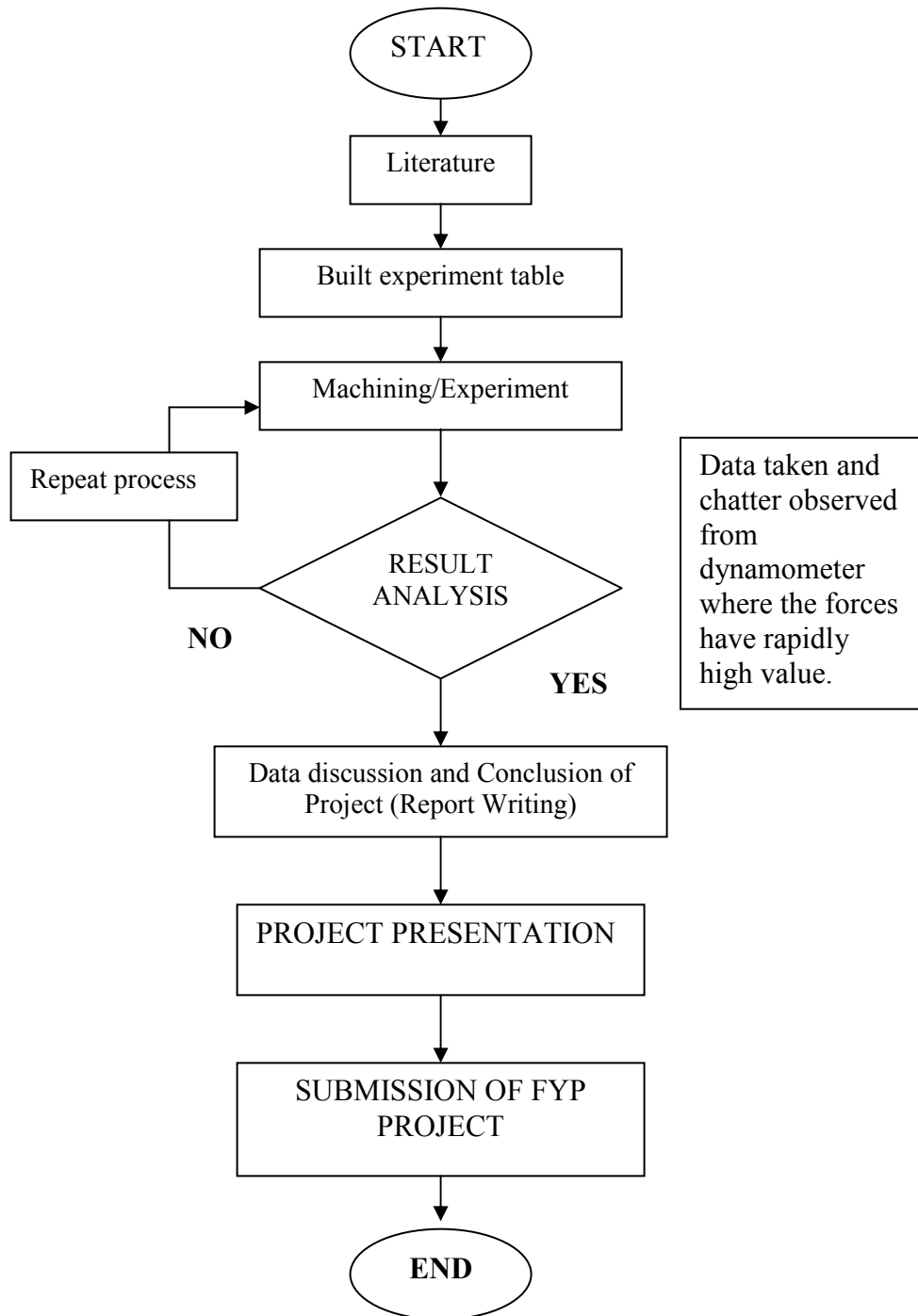


Figure 1.1: Project Flow Chart

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

The metal cutting technology growth rapidly and has enrolled as important aspect in manufacturing industry especially for aerospace industry and also in producing high precision part. In modern cutting technology, the trend continues unabated toward higher availability with more flexibility. Milling is the most important and widely useful operation process for material removal compared to turning, grinding and drilling. Milling can be defined as machining process in which metal is removed by a rotating multiple-tooth cutter with each tooth removes small amount of metal in each revolution of the spindle.

A machine tool directly influences the quality, productivity, and competitiveness of various production processes found in the automotive, aerospace, and die/mold industries [1, 2, 4 and 12]. To maximize the productivity in a machining process, both the speed at which the tools can machine without causing deterioration in the stability of system and accurate evaluations of machining stability are crucial [2].

The cutting process is given a great deal of weight in the development and production of products. Therefore, reducing the time required for the cutting process is one of the most effective methods of achieving rapid product development and improving productivity. The cutting speed must be increased to reduce the machining time, but this can provoke abnormal tool behavior such as chatter, which it is the most critical problems in the cutting process [1].

## 2.2 Chatter

Chatter is an abnormal tool behavior which it is one of the most critical problems in machining process and must be avoided to improve the dimensional accuracy and surface quality of the product [1, 2 and 4]. Its causes excessive tool wear, noise, tool breakage, and deterioration of the surface quality, it is essential to detect and prevent its occurrence. A varied uncut chip thickness in the cutting process induces variations in the cutting force, which repeatedly induce tool vibration. This phenomenon is called the regenerative effect and is a major source of chatter [1].

The end milling process is characterized by an interrupted cutting process in which the uncut chip thickness varies continuously. A varied uncut chip thickness in the cutting process induces variations in cutting forces, which repeatedly induce tool vibrations. This phenomenon is called the regenerative effect and is major source of chatter [1].

In the real world, machine tools are stiff as compared to the tools that go on them; however, they are not infinitely stiff. Understanding the dynamic characteristics of the tools becomes especially important when it comes to high velocity machining. This knowledge can help quantify vibration and lead to improvements in cutting performance. An understanding of chatter theories in milling cutters helps in recognizing dangerous cutting operations, optimizing the cutting parameters to eliminate chatter, and enhancing productivity [1 and 7]. The reflex to slow down the cutting process when chatter is audibly recognized can be detrimental to a cutter, especially when dealing with high velocity machining. In many cases, as this report will show, speeding up the cutting process may reduce or eliminate chatter most effectively. Developed an improved an uncut chip thickness model to consider the back-side cutting effect in unstable cutting states. Experimental results demonstrate that the chatter was predicted effectively by the developed dynamic cutting force model [1, 12, 13 and 14].

### **2.3 Dynamic cutting force**

In general, a cutting process is a closed loop system consisting of structural dynamics and cutting dynamics, and the chatter arises from the interaction between two dynamics. In other words, the relative displacement between the tool and workpiece brings about variations in the cutting forces due to the cutting dynamics, and the varied cutting forces bring about variations in the relative displacement due to the structural dynamics. An accurate cutting force model of ball-end milling is essential for precision prediction and compensation of tool deflection that dominantly determines the dimensional accuracy of the machined surface [1 and 15].

The modeling of cutting forces is often made difficult by the complexity of the tool/workpiece geometry and cutting configuration. Analytical cutting force is difficult due to the large number of interrelated machining parameters. The large number of interrelated parameters that influence the cutting forces (cutting speed, feed, and depth of cut, cutter geometry, and tool wear, physical and chemical characteristics of the machined part) makes it extremely difficult to develop a proper model.

Researchers [3], [4], [5] and [6] have been trying to develop mathematical models that would predict the cutting forces based on the geometry and physical characteristics of the process. However, due to its complexity, the milling process still represents a challenge to the modeling and simulation research effort.

Most previous research estimated the stability in flat end milling using only a simple tool path, such as a single line or corner paths. However, the calculation of dynamic forces in multi-tool paths must be performed to predict chatter in general NC machining operated by an NC code.

To calculate the dynamic cutting force in ball end milling, a structural dynamic model of the ball end mill was linked to a mechanistic cutting force model. Cutter runout

and penetration effects were also considered in our models to permit a more accurate evaluation of the machining [1].

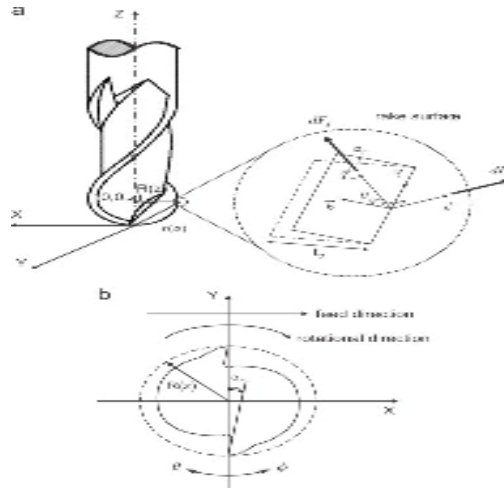


Figure 2.1: Cutting force model

## 2.4 Ball-End Milling

Ball end milling is one of the most widely used cutting processes in the automotive, aerospace, die/mold, and machine parts industries. Due to various reasons, such as structural, optimization or aesthetic points of view, nowadays, most of the industrial part geometries are becoming more and more complicated [1, 2, 4 and 12]. The recent advance in CAD/CAM systems and CNC machining centers allows us to supply this demand of machining very complex sculpture surfaces by ball-end milling. The importance of predicting the cutting forces in ball-end milling is evident. In the process planning stage, knowledge on the cutting forces helps the process engineers to select “appropriate values” for the process parameters. The prediction of cutting forces gives support in planning of the process, selecting of suitable cutting parameters for reduction of excessive wear, deformation and breakage of the tool, helps to design better fixtures which increase the quality of parts. The analytical cutting force model for ball-end

milling [6] can be also used for the prediction of the cutting forces in ball-end milling process.

## 2.5 Type of Cutter

As for the cutter tools material, High-speed steel (HSS) have become among the premier choices beside Solid Carbide and Coated Carbide cutter tools. Even though both Solid and Coated Carbide have better hardness and can undergo higher cutting speed and material removal rate without fracture, but HSS cutter tools are more effective due to high resistance to softening effects of heat in which they are capable to attain a high hardness at elevated temperature. Moreover, HSS a less distortion in heat treatment and also, they are less expensive if compared on prices with both Carbide cutter tools. The majority of HSS end milling cutters will be made from standard High Speed Steel (M7). For tougher machining applications cobalt end mills will be required. Cobalt is a M42 tool steel with an 8% cobalt content. It usually will require a M7. Another cutter commonly use is carbide. This tool material combines increased stiffness with the ability to operate at higher SFPM. Carbide tools are best for shops operating newer milling machines that do not have much chatter as the material can be brittle. Carbide end mills require a significant premium price over the cobalt end mills, but they can also be run at speeds 2 ½ faster than HSS end mills.



Figure 2.2: HSS 2-flute ball end mill

## 2.6 End mill tool

### DESIGN CRITERIA

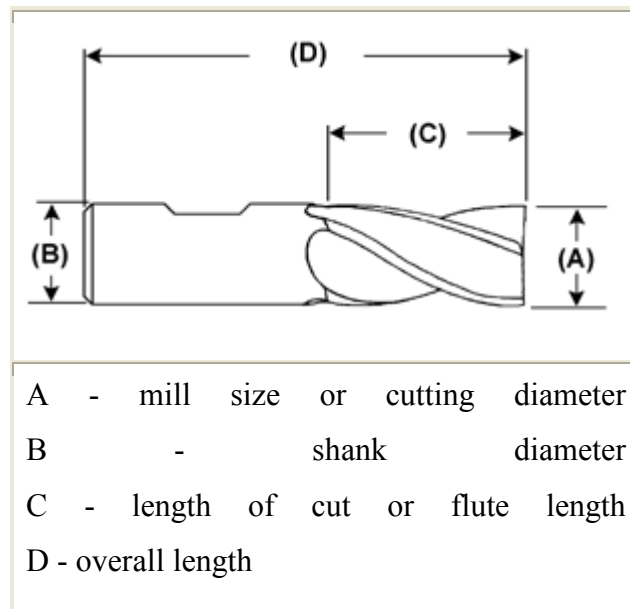


Figure 2.3: end mill criteria

- **Angular Edge** - That cutting edge that is a straight line, forming an angle with the cutter axis. The surface produced by a cutting edge of this type will not be flat as is the case with a helical cutting edge.
- **Axial Run out** - The difference between the highest and lowest indicator reading taken at the face of a cutter near the outer diameter.
- **Chamfer** - A short relieved flat installed where the periphery and face of a cutter meet. Used to strengthen the otherwise weak corner.

- **Chip Breakers** - Special geometry of the rake face that causes the chip to curl tightly and break.
- **Chip Splitters** - Notches in the circumference of a Corn cob style End mill cutter resulting in narrow chips. Suitable for rough machining.
- **Core Diameter** - The diameter of a cylinder ( or cone shape with tapered End mills) tangent to the flutes at the deepest point.
- **Counterbore** - A recess in a non-end cutting tool to facilitate grinding.
- **Cutter Sweep (Runout)** - Material removed by the fluting cutter (or grinding wheel) at the end of the flute.
- **Cutting Edge (A)** - The leading edge of the cutter tooth. The intersection of two finely finished surfaces, generally of an included angle of less than 90 degrees.
- **Cutting Edge Angle** - The angle formed by the cutting edge and the tool axis.
- **Differential pitch cutters** - A specifically designed variation in the radial spacing of the cutter teeth. This provides a variation in tooth spacing and can be beneficial in reducing chatter. This concept is based on reducing the harmonic effect of the tool contacting the part in an exact moment of vibration.
- **Entrance Angle** - The angle formed by a line through the center of the cutter at 90 to the direction of feed and a radial line through the initial point of contact. As this angle approaches 90 degrees the shock loading is increased.
- **Entrance Angle: Ramp-in** - Angle or radius value to enter the cutter into the part surface.